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N78-13263

STORAGE AND FEEDING OF COAL

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ABSTRACT

Reliable feeding of coal from storage bins to process requires the knowledge of the behavior of coal during flow. Sponsored by AIME Research, in flow of bulk solids was undertaken in the 1950's by Jenike, and led to the development of flow ability testing equipment and of the 'Mass Flow" concept of design for reliable flow. The theory has since been expanded to two-phase, solids-gas system, and has found world wide application in the design of storage and feeding systems.

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by

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HISTORICAL

In 1954 the Coal and Minerals Beneficiation Divisions of AIME sponsored a study on the "Flow of Bulk Solids" proposed by Dr. Andrew W. Jenike. The Engineering Foundation provided seed money. The University of Utah, the American Iron and Steel Institute and the National Science Foundation provided the bulk of the research funds. Under Jenike s leadership, a Bulk Solids Flow Laboratory was set up at the University of Utah in 1956; by 1962 a theory of flow of bulk solids as well as equipment to measure the pertinent solids properties had been developed and proved in industrial applications to storage bins and feeders.

The design method has been verified through* extensive experimental work, especially in the United Kingdom [42] and Germany [25], and applied to hundreds of storage plants and reactor vessels all over the world.

In the past ten years the theory of flow has been extended to two-phase, solid-gas systems.

FEEDING

Consider coal being fed from a storage bin or hopper to a process. The feeder is designed to feed at a given rate against a given gas pressure. But, for the feeder to operate, coal must flow from the hopper into the feeder uniformly at the given rate. To assure such flow it is necessary that: (a) the hopper leading to the feeder be sufficiently steep and smooth, (b) the inlet area into the feeder be sufficiently large, and (c) the inlet area be fully live and effective. These conditions are rarely satisfied unless the bin and feeder have been designed on the basis of the flow theory supported by measurements of the flow properties of the used coals.

* Numbers in brackets refer to references at end of paper

FLOW PATTERNS

When the hopper, i.e. the converging part of a storage bin, is sufficiently steep and smooth and the hopper outlet larger than critical for the least free-flowing coal in question, coal flows out of the bin by gravity without any stagnant regions in the bin. Such a flow pattern is referred to as "mass-flow." A mass-flow bin is shown, and its properties listed, in Fig. 1.

If the hopper is not sufficiently steep and smooth, coal flows only in a narrow channel which forms within stagnant coal. This flow pattern is referred to as "funnel flow." The critical outlet dimensions of a funnel flow hopper are always larger than those of a mass-flow hopper, sometimes, several times larger. A funnel-flow bin is shown, and the properties listed, in Fig. 2.

The regions of mass-flow are indicated approximately in Figures 3 and 4 as a function of the hopper slope angle and the friction angle between coal and the wall of a circular cone and a long wedge, respectively.

CRITICAL HOPPER OUTLET

Coal arches across a hopper outlet when the strength of the coal is greater than the stresses which act in the arch. The flow criterion follows from that observation: coal will flow provided its cohesive strength is less than the stresses in a potential obstruction to flow (arch, stable rathole). The strength of a given coal is a function of: (a) the degree of compaction, which is measured by the consolidating pressure applied during compaction, (b) time of application of the consolidating pressure, (c) moisture content, (d) temperature. The function of strength versus consolidating pressure, under given conditions (b), (c) and (d), is referred to as the flow-function FF, Fig. 5. Evidently, the higher the FF - line lies, the more strength a material develops and the less free-flowing it is. The method used to measure the flow-function and the wall friction angle is described in references [2 and 11]. The theory of one-phase, solids only, flow is derived in references [1,3,5, 6,7,8,13,14,27] and summarized in reference [11]. Various aspects of testing materials and proper bin and feeder design are described in references [9,10,12,17,20,22,29,32,33-35].

APPLICATIONS

A typical application of the theory results in a sketch such as shown in Fig. 6. This gives the bin and feeder dimensions, the material and surface finish of the hopper walls [e.g. 304SS-2B finish] and the screw size, rpm and horsepower. Note the design of the screw in which the volumetric flow rate increases from zero to maximum in the direction of coal flow within the length L of the feeder inlet. This is necessary to make the hopper outlet fully effective and permit mass flow.

Other applications are described in the references: loads on bin walls [24,26,37-39]; design of moving bed reactors [30]; briquetting [15,16,28]; flow-corrective inserts [18,19,21]; in-bin blending [31]; bin vibrations [41]; underground mining [4].

TWO-PHASE, SOLID-GAS SYSTEMS

In the past ten years, the theory of single-phase solids flow has been extended to two-phase solids-gas systems. This became necessary in the calculation of flow rates of powders out of hoppers. During the flow of a solid down a vessel, there occur significant bulk density changes, as the solid first compacts under increasing consolidating pressures, then expands toward the hopper outlet. The volume of the pores changes correspondingly giving rise to gas (air) pressure changes within the pores. This leads to significant gas pressure gradients in fine, impermeable materials. These gradients add (or subtract) to the gravity forces which cause flow, and thus significantly affect the flow rate [23,40], as well as the critical outlet dimensions for flow without arching and the rate of settlement of powders [36]. Few analyses and results of applications of the two-phase theory have been published to date, most of the work having been of proprietary nature.

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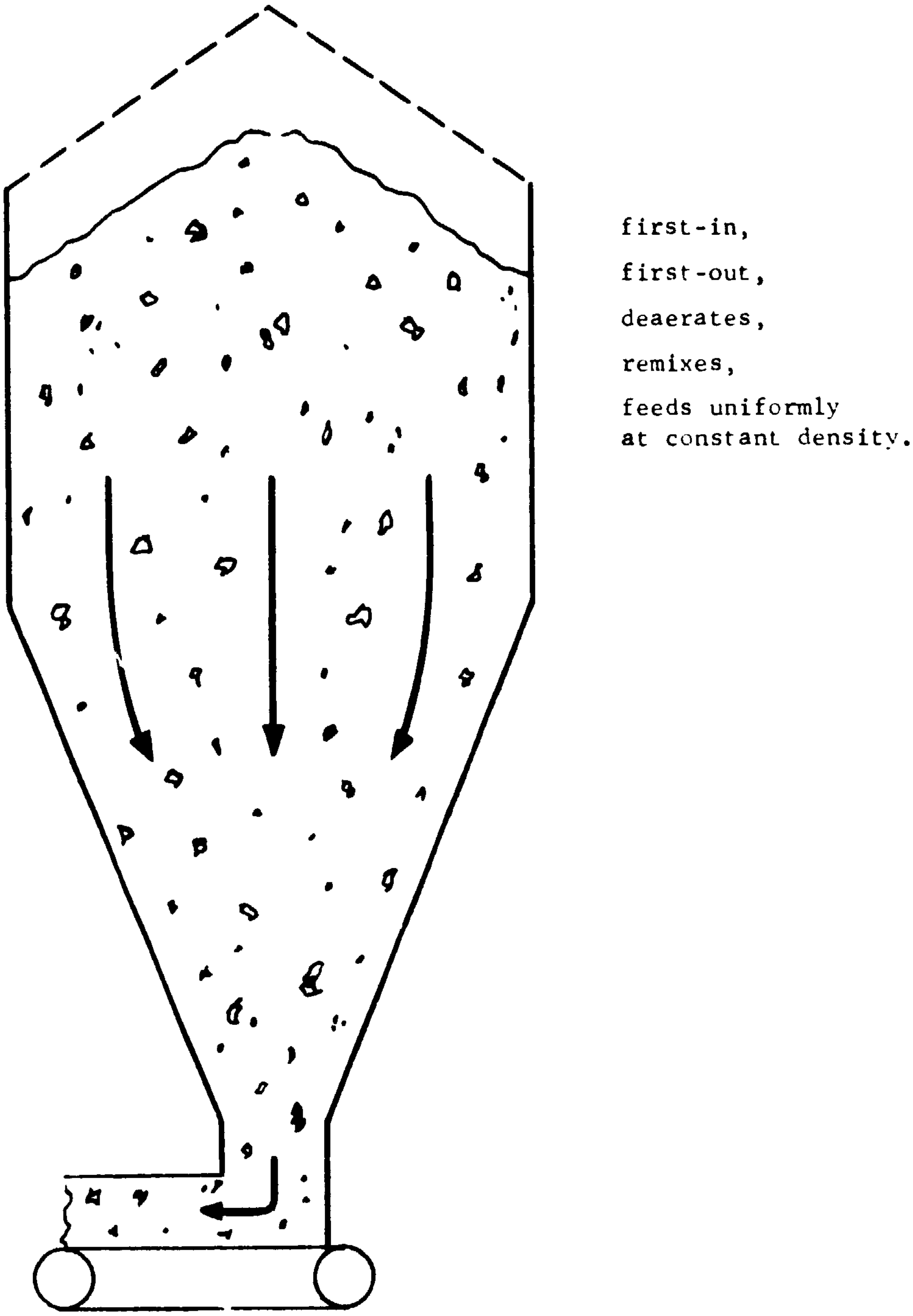
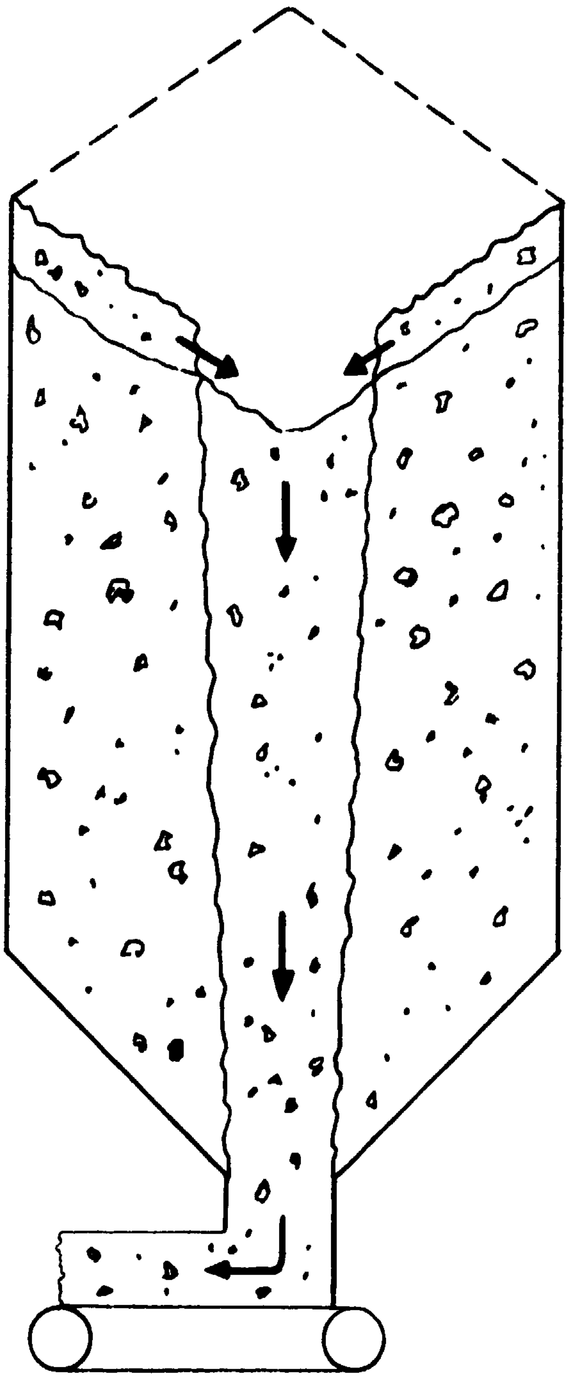


Fig. 1 Mass Flow Bin



first-in,
last-out,
segregates,
ratholes,
flushes.

Fig. 2 Funnel Flow Bin

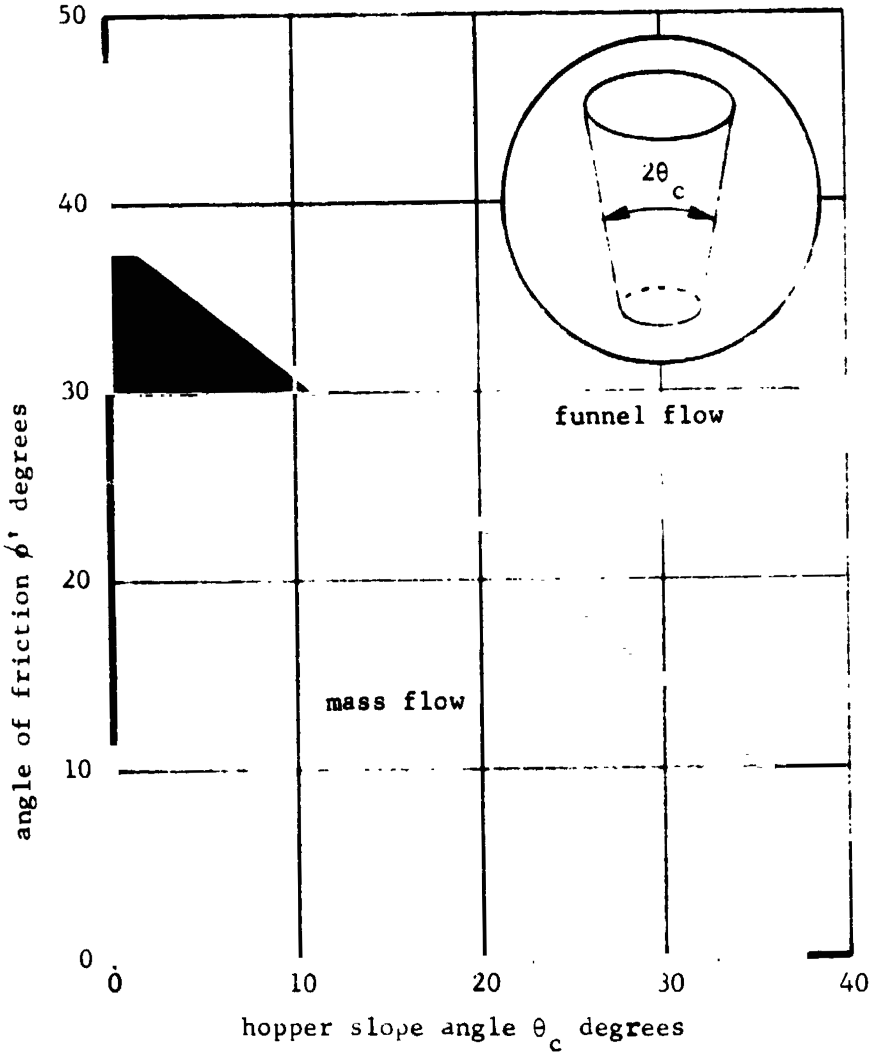


Fig. 3 Ranges of Mass Flow and Funnel Flow in Conical Hoppers

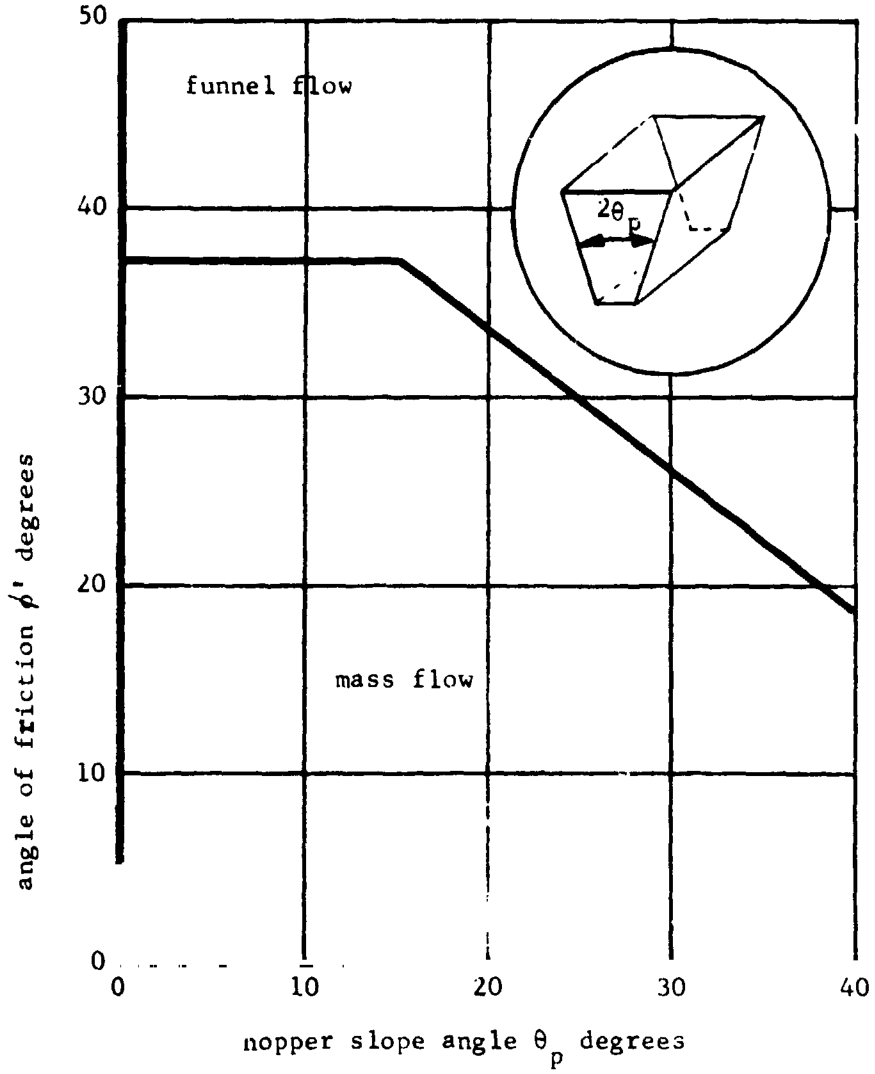


Fig. 4 Ranges of Mass Flow and Funnel Flow in Plane Flow Channels

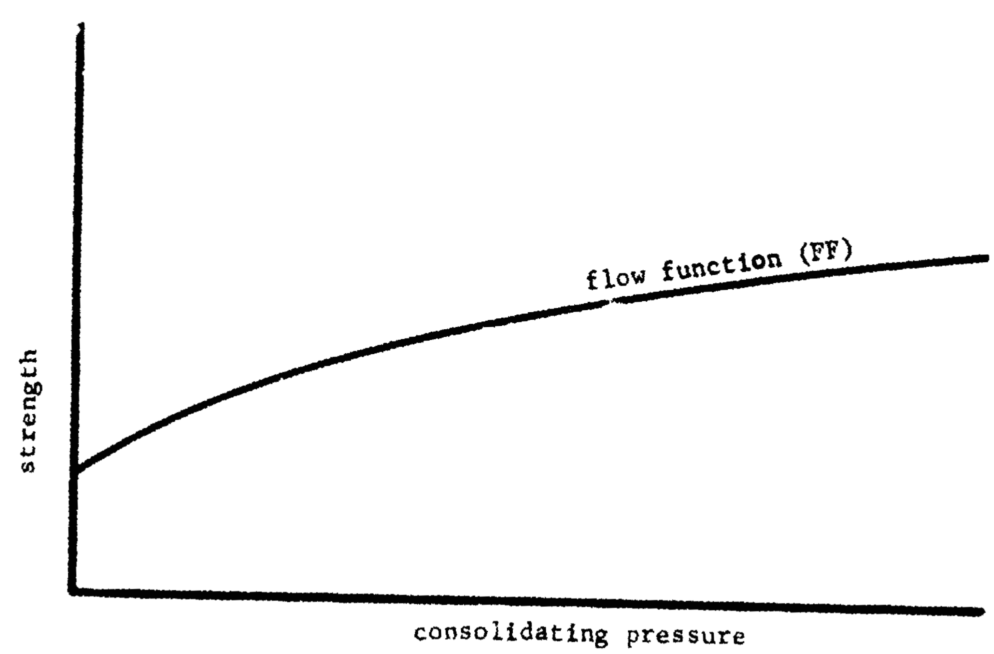


Fig. 5 Relationship Between Strength and Consolidating Pressure for a Typical Bulk Solid

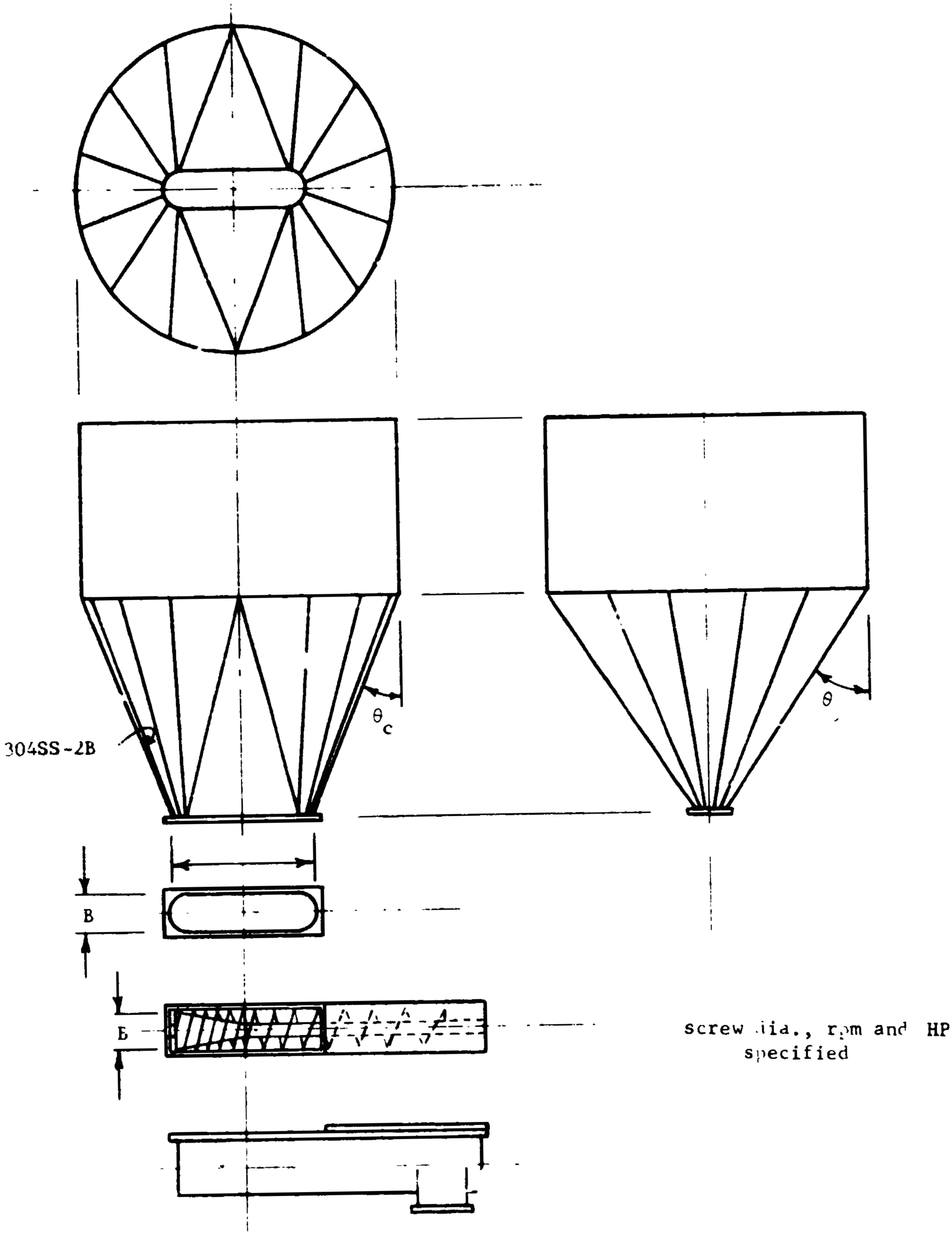


Fig. 6 Typical Mass Flow Bin and Feeder Design